NASA TECHNICAL TRANSLATION NASA TT F-12,363

NASA TT F-12,363

EXPERIMENTAL INVESTIGATION OF DISTRIBUTION PARAMETERS IN SINGLE-PHASE AND DOUBLE-PHASE SUBSONIC PLASMA FLOWS

N.S. Surov

Translation of: "Eksperimenta'noye issledovaniye raspredeleniya parametrov v odnofaznoy i dvukhfaznoy dozvukovykh plazmennykh struyakh"
Teplofizika vysokikh temperatur, Vol. 7, No. 2, pp. 304-312, 1969.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 SEPTEMBER 1969

EXPERIMENTAL INVESTIGATION OF DISTRIBUTION PARAMETERS IN SINGLE-PHASE AND DOUBLE-PHASE SUBSONIC PLASMA FLOWS

N.S. Surov

ABSTRACT: An experimental investigation is made of the distribution of velocity and temperature in single-phase and double-phase (the degree to which it is double-phased is up to about 4.4) plasma streams. It is shown that the introduction of a condensed phase into the plasma flow can significantly decrease the temperature and velocity of the gas. It is established that an intense decrease in the stream parameters takes place downstream. It is also shown that the parameter distribution in the lateral cross sections of the main part of the stream can be adequately described by the corresponding Schlichting curves. Values are found for the Reynolds number determining the change in the flow regime in an argon plasma flow on the cross section of a nozzle.

Free single-phase and double-phase plasma streams have found wide application in science and technology (the vaporization of refractory materials, the production of powders, the synthesis of materials in plasma streams etc.). In order to choose the optimal regimes for understanding these processes, we need to know the distribution of temperature and velocity both in different cross sections and along the axis of the plasma streams. /304

There are many experimental and theoretical works, generalized in [1, 2], which investigate isothermic or slightly heated gas flows. However, the flow motion of a plasma has been studied very little up to the present time. Certain results concerning single-phase plasma in air or annular wakes of another gas were obtained in references [3-6]. No one has yet obtained data on heterogeneous plasma streams.

In practical work with heterogeneous plasma streams the influence of a condensed phase on the hydrodynamic parameters of the stream is usually not taken into account, which naturally is not always valid. In relation to this fact, in this article we will study the problem of the distribution of temperature and velocity of the gas in single-phase and double-phase stationary subsonic plasma streams flowing into the atmosphere, and establish the influence of the degree to which it is double-phase on the value and distribution of these parameters. (We will define the ratio $K = G_b/G_a$ as the degree to which it is double-phase; G_b is the mass flow of the

* Numbers in the margin indicate pagination in the foreign text.

condensed phase across a lateral cross section of the stream; G_a is the mass flow of gas across the same cross section.)

Description of the Apparatus. The experiments were made on a pulse plasma source with a vortex supply of the working medium and a nozzle diameter equal to $6 \cdot 10^{-3}$ m. Powder was injected into the plasma flow through an aperture in the wall of the nozzle. A diagram of the apparatus for conducting the experiment is shown in Figure 1.

The direct current electric arc heater (1) was placed horizontally on the frame (10) along which the heater could be shifted in an axial direction. Energy was supplied to the source from a line across a selenium rectifier, a battery of ballast rheostats and a control panel, on which the measuring and starting equipment were located. The working medium (argon, symbol "A") entered from the tank also through the control panel. With investigation of double-phase streams, a powder (tungsten carbide) was introduced into the stream using a special feeder (2). The flow rate of the powder ($2.9 \cdot 10^{-3}$ kg$\cdot$sec^{-1}) was held constant in all experiments since we placed the dosage apparatus of the feeder in the same place. The dimension of the powder particles was kept constant by sifting through a special screen. /30

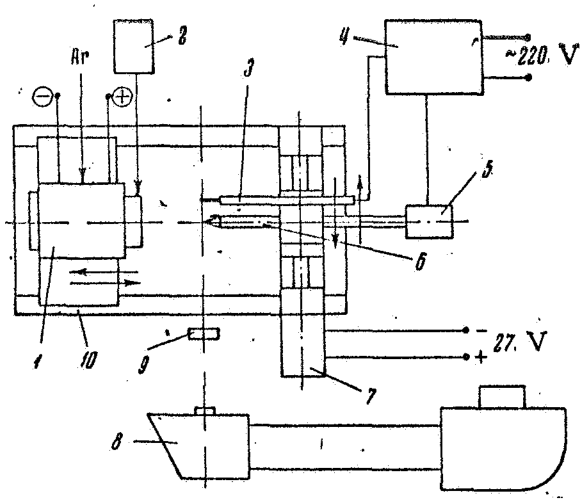

Fig. 1. Diagram of the Experimental Apparatus.

The microthermocouple (3) and the water-cooled total pressure sensor (6) were shifted across the stream slowly ($(4-8) \cdot 10^{-3}$ m/sec) using an electric motor (7). The electric signals from the thermocouple and the manometric device (5) were recorded on the tape of an MPO-2 oscillograph (4). To record the spectra of the luminous part of the stream we used an ISP-51 spectrograph (8) with a UF-85 camera. The stream was focused on the slit of the spectrograph using a lens (9). The spectrum of the iron arc was obtained using a PS-39 generator and as a source of standard radiation we used a SI-10 tungsten ribbon-filament lamp.

The experiments were made in the following order. With a given fixed power supplied to the plasmatron (10 and 15 kw), the flow rate of the working medium was changed by steps ($0.66 \cdot 10^{-3}$; $1.09 \cdot 10^{-3}$; $1.66 \cdot 10^{-3}$ kg/sec); for each flow rate we investigated the distribution of temperature and velocity in the cross sections of the stream located at distances: 10^{-3}; $12 \cdot 10^{-3}$; $15 \cdot 10^{-3}$; $75 \cdot 10^{-3}$; $135 \cdot 10^{-3}$ m from the cross section of the nozzle. Measurement of the distribution of the parameters was made under the same regimes for both homogeneous and heterogeneous streams.

The Measurement Procedure. Measurement of Temperature in the Luminous Part of the Stream. The temperature on the axis of the luminous part of the plasma stream (up to $\sim 15 \cdot 10^{-3}$ m from the cross section of the nozzle) was computed by measuring the absolute intensity of the lines emitted by argon in the wavelength range λ = 4000 -4300 Å.

On the assumption that the plasma in the stream under atmospheric pressure is in a state of thermodynamic equilibrium [3], the intensity of the line radiation of an optically thin layer of gas is computed by the relationship, given in reference [3] and in the dissertation of V.N. Kolesnikov[1]

$$I = \frac{1}{4\pi} A_n{}^m N_0 \frac{g_m}{g_0^{(i)}} lh\nu \exp\left(-\frac{E_m}{kT}\right), \quad (1)$$

$A_n{}^m$ is the probability of transition from an excited state with a quantum number m to a state with a quantum number n, N_0 is the concentration of neutral particles per unit of volume, g_m is the static weight of state m, $g_0^{(i)}$ is the static sum by the states of the radiating atoms, E_m is the excitation energy of level m, T is the absolute temperature of the gas, h is Planck's constant, ν is the radiation frequency, l is the length of the radiating layer, k is Boltzmann's constant. /30

We assume that equation (1) is also valid for double-phase plasma streams, since in the conditions of the experiment, the volume part of the condensed phase in the stream remained small ($\sim 2 \cdot 10^{-5}$).

The absolute intensity of the argon lines, chosen for measurement (λ = 4158 Å, λ = 4259 Å, λ = 4300 Å), was determined by comparison with the spectral intensity of a standard radiator. To do this, together with the spectrum of the stream, we photographed the spectrum of a SI-10 standard lamp and then the intensity of the lines was measured in units of the intensity of the standard radiation, measured on the same wavelengths (cf. [3] and the dissertation of V.N. Kolesnikov). The values of the monochromatic coefficients of blackness of tungsten necessary for the calculation were taken from [7]. The obtaining of the spectra of the stream and the standard, interpretation of the photographic material and measurement of the radiation intensity were made with strict observance of the respective procedures using the usual equipment [3, 8, 9]. The physical constants for these lines were borrowed from reference [9] and the value of N_0 was calculated by the Sakh equation. Variations in the value of $g_0^{(i)}$ as a function of temperature were not taken

---

[1] V.N. Kolesnikov: Dissertation, Fiz. Instit. Akad. Nauk SSSR, 1962.

into account. On the assumption of axisymmetry of the stream, the effective optical thickness of the radiating layer was determined using the Abel transformation [3]. Equation (1) was solved with respect to temperature on a "Ural-3" computer by the method of successive approximations. The temperature on the axis of each cross section was determined as the arithmetic mean of the results of the calculation according to two, and, in certain cases, three lines.

We found the temperature distribution by radius from the relationship [3]

$$\frac{I}{I_0} = \frac{N g_0^{(i)}(T_0)}{N_0 g_0^{(i)}(T)} \exp\left[-\frac{E_m}{k}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right], \tag{2}$$

where I_0, N_0, $g_0^{(i)}$ (T_0), T_0 are respectively the spectral intensity of the line, the number of atoms per unit volume, the static sum of the atoms by the states and the temperature at the axis of the stream, and I, N, $g_0^{(i)}$ (T), T are the same values at an arbitrary point of a given cross section.

The ratio I/I_0 was determined from the spectrogram and N and N_0 were determined according to the Sakh equation. Equation (2) was also solved with respect to T on a "Ural-3" computer by the method of successive approximations. As estimates show, the errors in determining temperature by this method do not exceed ~ 4-5%.

Measurement of the Gas Temperature in the Nonluminous Part of the Stream. The temperature distribution of the gas far from the cross section of the nozzle, where the stream has a relatively low temperature, was investigated using an unshielded chromel-alumel microthermocouple whose readings during motion across the stream were recorded on the tape of an MPO-2 oscillograph. According to the obtained oscillograms using calibration curves, we plotted the actual temperature distribution by cross section of the stream. The thermocouples were calibrated according to the melting points of zinc and aluminum in a loop assembly with which the thermocouples then operated.

Since an unshielded thermocouple, immersed in a gas stream, indicates only its own internal temperature [10], we took into account the deviations in the indications of the thermocouple, caused by its thermal inertia, radiation, stagnation of the flow and the heat removal from the junction, so that when interpreting the experimental data we might obtain the thermodynamic temperature of the flow. We /30 made the corresponding corrections in the results wherever it seemed necessary.

An analysis showed that the greatest error in measuring the temperature in the center of the stream (roughly up to 2/3 radius) by the given method did not exceed ~4%. The relative errors in measurement at the boundary of the stream were significantly greater since the value of temperature is small near the boundary.

Measurement of Velocity Distribution in a Plasma Stream. There are a great number of methods for measuring the velocity of a gas in a flow [11]. To determine the velocity in the stream we used a specially developed, water-cooled total pressure sensor, whose spout was coated with tungsten and which was cooled indirectly from a water-conducting system. The diameter of the receiving aperture of the sensor was $(0.9-1.0)\cdot 10^{-3}$ m. As the sensor was moved across the stream, the readings of the manometric device, which registered the excess pressure in the flow, were recorded on the tape of an oscillograph or read visually.

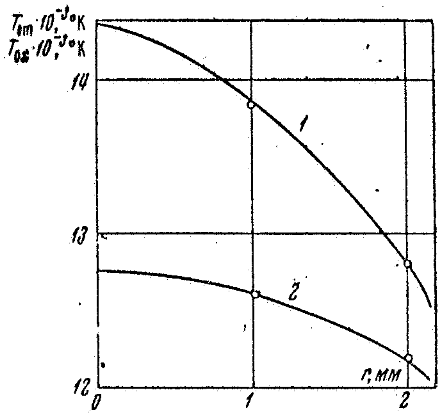

Fig. 2. The Temperature Distribution by Radius on the Cross Section of the Nozzle in Single-Phase (1) and Double-Phase (2) Streams: $W = 15$ kW, $G_a = 1.09\cdot 10^{-3}$ kg/sec, $x = 10^{-3}$ m, $G_b = 0$ (1), $G_b = 2.9\cdot 10^{-3}$ kg/sec (2).

In connection with the fact that the statistical pressure in a free, subsonic plasma flow (with an accuracy of about 1% [6]) is equal to the pressure in the surrounding medium, we can assume that in the experiments we measured the kinetic energy across the stream. In this case from the Bernoulli law and the equation of state of the gas we obtained the following relationship for determining the velocity (or pressure in the surrounding medium $\sim 9.8\cdot 10^5$ nm^2) [11]:

$$w = \left(0.17\frac{pT}{\mu(1+\varepsilon)}\right)^{1/2}. \tag{3}$$

Here w is the velocity of the gas at an arbitrary point, p is the kinetic energy, T is the temperature of the gas, μ is the molecular weight of the gas, ε is a correction for the compressability of the gas.

Positing that with mixing of the argon plasma stream with air, the argon concentration distribution in it has the same character as the temperature distribution due to the identity of the transfer mechanisms [1, 4, 6] and bearing in mind the preliminary experimental data on temperature distribution in double-phase and single-phase streams far from the cross section of the nozzle, we can calculate the molecular weight of the gas at an arbitrary point in the flow. In this case equation (3) takes the form

$$w = \left(0.17pT\left\{\frac{T_m}{T_{0m}\mu_a}\left[1-\left(\frac{y}{r}\right)^{3/2}\right] - \frac{T_m}{T_{0m}\mu_{air}}\left[1-\left(\frac{y}{r}\right)^{3/2}\right] + \frac{1}{\mu_{air}}\right\}\right)^{1/2}, \tag{4}$$

where T_m is the temperature of the gas on the axis of an arbitrary cross section, T_{0m} is the temperature of the gas on the axis of the initial cross section, μ_a is the molecular weight of argon, y is the distance of the given point from the axis of the stream, r is

the thermal radius of the stream, μ_{air} is the molecular weight of the air. We did not introduce a correction for compressibility of the gas into (4), however, it was introduced into the results of calculations according to (4) in all cases when the Mach number of the flow in the examined point satisfied the inequality $M \gtrsim 0.5$. /30
The correction for compressibility of the gas was determined according to the relationship [11] $\varepsilon = 1/4\ M^2$.

When solving (4) the molecular weights of argon and air were taken on the basis of tables data and the remaining values were taken from the experiment. On the cross section of the nozzle relationship (4) is valid if we posit that $\mu_{air} = \infty$, $y = 0$, since the concentration of air in this cross section is equal to zero. In the process of interpretation of the experiments, equation (4) was solved on a "Ural-3" computer. As estimates show, the errors in determining the velocity at the center of the stream (up to about 2/3 radius) by this method did not exceed $\sim$ 6%.

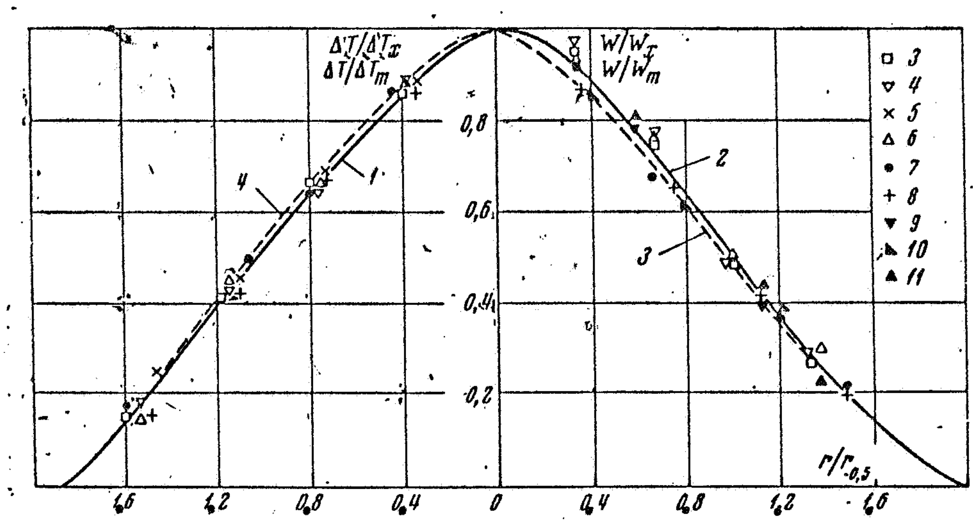

Fig. 3. Distribution of the Relative Excess Temperature (1) and the Relative Velocity (2) by Radius of the Stream: 1: W = 15 kW, G_a = $1.69\cdot10^{-3}$ kg/sec^{-1}, x = $75\cdot10^{-3}$ m, G_b = 0 (3), G_b = $2.9\cdot10^{-3}$ kg/sec^{-1} (7); W = 10, G_a = $1.69\cdot10^{-3}$, x = $75\cdot10^{-3}$, G_b = 0 (4), G_b = $2.9\cdot10^{-3}$, (6); W = 10, G_a = $0.66\cdot10^{-3}$, x = $75\cdot10^{-3}$, G_b = 0 (8), G_b = $2.9\cdot10^{-3}$, (5). 2: W = 10, G_a = $1.69\cdot10^{-3}$, x = $12\cdot10^{-3}$, G_b = 0 (6), G_b = $2.9\cdot10^{-3}$, (4); W = 15, G_a = $1.69\cdot10^{-3}$, x = $15\cdot10^{-3}$, G_b = 0 (7), G_b = $2.9\cdot10^{-3}$, (10); W = 15, G_a = $1.09\cdot10^{-3}$, x = $15\cdot10^{-3}$, G_b = 0 (8); W = 10, G_a = $0.66\cdot10^{-3}$, x = $75\cdot10^{-3}$, G_b = 0 (9), G_b = $2.9\cdot10^{-3}$, (11)

The Results of the Experiments and Discussion. The Distribution of the Parameters in the Lateral Cross Sections of the Stream. Figure 2 shows the temperature distribution of the plasma by radius on the cross section of the nozzle in double-phased and single-phased streams for one of the examined regimes. It is clear from the graph that the introduction of powder into the flow leads to a substantial decrease in temperature and to a more even temperature distribution throughout the cross section.

A typical distribution of the relative excess temperature and also relative velocity by radius of single-phased and double-phased streams based on section is illustrated in Fig. 3. Along the abscissa we plotted the ratio of the flow radius to that radius $r_{0.5}$ where the excess temperature $\Delta T_{x,m}$ or velocity $w_{x,m}$ are equal to one half their value on the axis of the chosen lateral cross section of the stream (the index x refers to the parameters of a double-phase stream, m refers to the parameters of a single-phased stream). The experimental curves 1, 2 of excess temperature and velocity distributions coincide quite satisfactorily with the corresponding Schlichting curves 3, 4, even in the case of a slightly heated stream [1].

The data of Figure 3 show that in the examined variation range of the parameters the presence of a condensed phase in the plasma stream has no influence at all on the temperature and velocity distributions in the cross section of the stream. It is clear that, in conjunction with this fact, the volume part of the condensed phase in the stream always remains small (no more than about $2 \cdot 10^{-5}$).

The results of measurements of the temperature and velocity distributions in the lateral cross sections of the stream allows us to establish that the outer thermal and dynamic boundaries of the plasma stream in air are roughly rectolinear, do not coincide (the thermal boundary is significantly farther from the axis of the stream) and form with the axis of the stream a substantially larger (by about 2 times) angle than the corresponding boundaries in a slightly heated stream. We did not detect any influence of the condensed phase on the position of the boundaries of the stream in the area of the examined regimes. /30

Figure 4 shows the relative velocity profiles of single-phase and double-phase streams on the cross section of the nozzle. Those parts of the experimental curves 2-5 shown by dashes were plotted using an interpolated temperature.

The regime of motion in the examined cross section was determined by comparison of the experimental velocity distribution profile with the corresponding theoretical profiles with laminar (curve 6) or developed turbulent (curve 1) flows in a circular tube. The problem of the conditions for transition in this cross section of a laminar flow to a turbulent one (or vice-versa) was solved using the curve shown in Figure 5.

We plotted along the abscissa here the Reynolds number of the flow on the cross section of the nozzle, and along the ordinate we plotted the ratio of the velocity u_2 with laminar motion at the point at a distance of $2 \cdot 10^{-3}$ m from the axis of the stream to the measured velocity w_2 at the same point. For our calculation of the Reynolds number of the flow we borrowed the relationship between

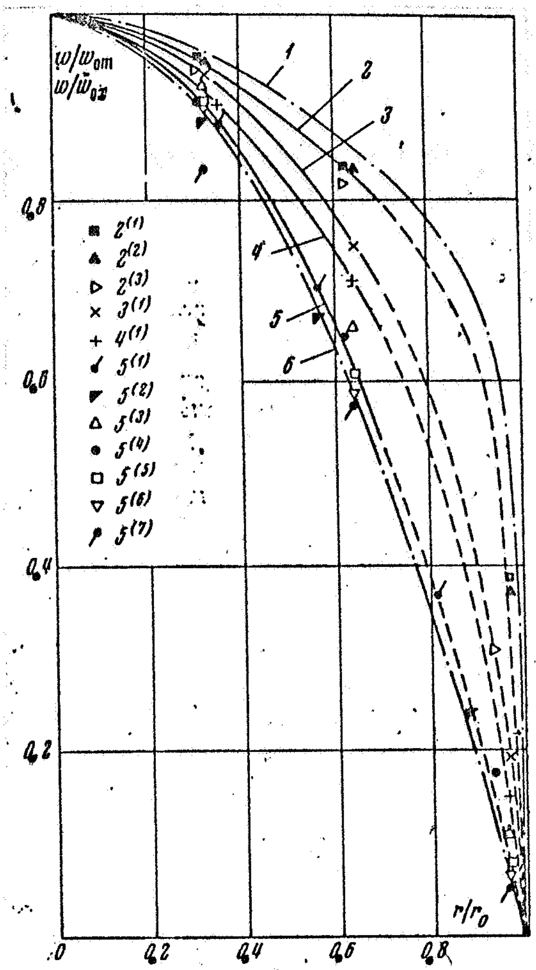

Fig. 4. Distribution of the Dimensionless Velocity by Relative Radius on the Shear of the Nozzle ($x = 10^{-3}$ m): 1. A Developed Turbulent Flow; 2: $2^{(1)}$ (W = 15 kW, $G_a = 1.69 \cdot 10^{-3}$ kg/sec^{-1}, $G_b = 2.9 \cdot 10^{-3}$ kg/sec^{-1}); $2^{(2)}$ (W = 10, $G_a = 1.69 \cdot 10^{-3}$, $G_b = 2.9 \cdot 10^{-3}$); $2^{(3)}$ (W = 10, $G_a = 1.69 \cdot 10^{-3}$, $G_b = 0$); 3. $3^{(1)}$ (W = 10, $G_a = 1.09 \cdot 10^{-3}$, $G_b = 2.9 \cdot 10^{-3}$); 4. $4^{(1)}$ (W = 15, $G_a = 1.09 \cdot 10^{-3}$, $G_b = 2.9 \cdot 10^{-3}$); 5: $5^{(1)}$ (W = 15, $G_a = 0.66 \cdot 10^{-3}$, $G_b = 2.9 \cdot 10^{-3}$) $5^{(2)}$ (W = 15, $G_a = 1.09 \cdot 10^{-3}$, $G_b = 0$) $5^{(3)}$ (W = 10, $G_a = 1.09 \cdot 10^{-3}$, $G_b = 0$) $5^{(4)}$ (W = 15, $G_a = 1.69 \cdot 10^{-3}$, $G_b = 0$) $5^{(5)}$ (W = 10, $G_a = 0.66 \cdot 10^{-3}$, $G_b = 2.9 \cdot 10^{-3}$) $5^{(6)}$ (W = 10, $G_a = 0.66 \cdot 10^{-3}$, $G_b = 0$) $5^{(7)}$ (W = 15, $G_a = 0.66 \cdot 10^{-3}$, $G_b = 0$); 6. Laminar flow

the dynamic viscosity and the temperature from reference [12]. In the process of constructing the graph for comparison we determined the Reynolds number by two methods: by axial (the triangles) and mean-mass (the dots) parameters.

Analysis of this function shows the following. First, with Re $\lesssim$ 630, the plasma flow on the cross section of the nozzle is laminar, and with Re $\lesssim$ 850 it is turbulent. In the interval 630 $\lesssim$ Re $\lesssim$ 850 there is a transitional regime of flow. Secondly, the indicated boundaries of the existence of the different regimes of motion are found to be the same regardless of the method of determining the Reynolds number (by axial or mean-mass parameters of the /31
plasma flow).

It is interesting to note that if in calculating the Reynolds number we take advantage of the viscosity of the gas with temperature of the wall of the nozzle, then the above indicated Reynolds numbers become near to the analogous values, characterizing the regimes of motion of a cool gas. Reference [13] also pointed out this fact. As follows from the experimental data, the admixture of powder to the plasma flow has a substantial influence on the nature of the flow and can lead to a change in the regime of motion.

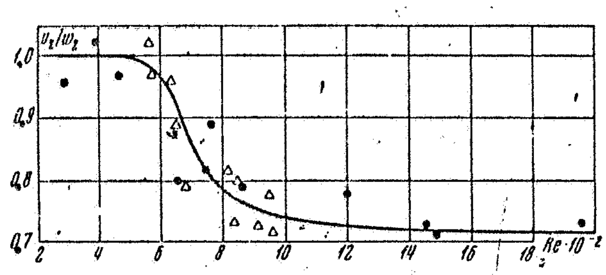

Fig. 5. The Change in the Regime of Flow on the Cross Section of the Nozzle as a Function of the Reynolds Number.

In concluding this section we should say that a check of the validity of the parameter distributions presented here, made according to the energy and mass balance of momentum in the stream, showed that these balances were valid within the limits of accuracy of the experiments and the corresponding calculations.

Change in the Parameters along the Axis of the Stream. The excess temperature distribution along the axis of single-phased and double-phased streams is shown in relative coordinates in Figure 6; an analogous graph for the relative velocity is shown in Figure 7. The dots denote the greatest variance of the data in a heterogeneous stream and the circles denote the greatest variance in a homogeneous stream (x is the distance from the cross section of the nozzle; d is the diameter of the nozzle).

In plotting the distribution of axial temperature in the section $15 \cdot 10^{-3}$ m < x < $75 \cdot 10^{-3}$ m, we used additional points, determined from the melting point of a thin ($d_p = 0.5 \cdot 10^{-3}$ m) tungsten wire which was introduced into the stream. The wire was placed along the

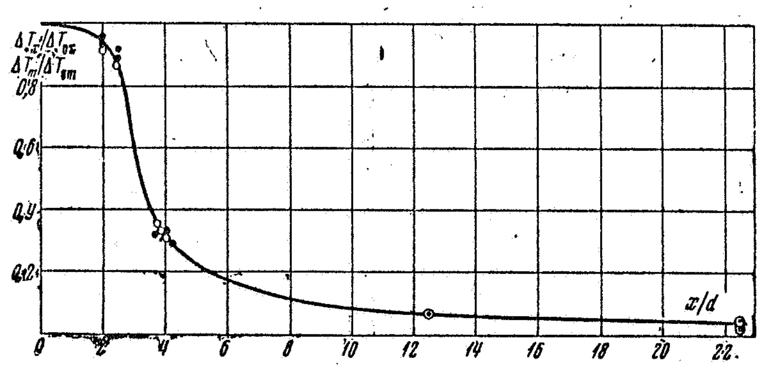

Fig. 6. The Change in the Dimensionless Excess Axial Temperature of the Gas Along the Stream.

center of the nozzle, introduced into the stream and shifted along its axis toward the nozzle. We posited that at the point at which the wire began to melt, its temperature would be equal to 3340 ± 15° C [14]. The thermodynamic temperature of the gas at this point was determined with a correction for radiation of the wire, heat dissipation along the wire and stagnation of the flow. As our estimates showed, the errors in measurement by the indicated method do not, apparently, exceed about 16%.

We can draw the following conclusions from an examination of the graphs. The decrease in the axial parameters both in homogeneous and in heterogeneous streams, within the accuracy of the experimental errors, can be represented as one curve. There is an initial /31 section in the stream (length $x \approx d$) where the temperature and velocity drops are small. With subsequent increase in the distance from the cross section of the nozzle up to $x \approx 7d$, the parameters of the stream decrease very intensively (much more rapidly than in the case of slightly heated streams [1, 2]); temperature decreases much more than velocity. The physical mechanism of so significant a change in the parameters of argon plasma streams moving in air, is not yet clear. However, apparently, we can assume that in addition to possible existence in the stream of large-scale turbulent pulsations [4], leading to rapid erosion of the stream, the substantial temperature drop is caused by energy losses of the stream to dissociation of the air which is drawn into the stream.

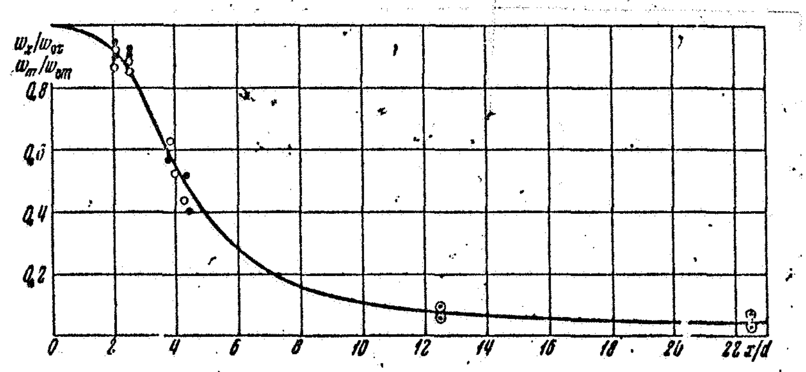

Fig. 7. The Relative Velocity as a Function of the Relative Diameter Along the Axis of the Stream.

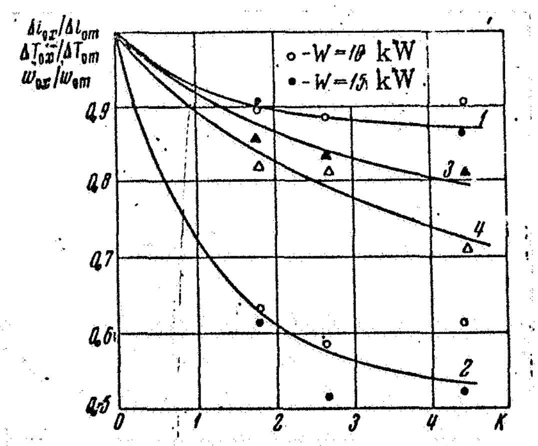

Fig. 8. The Influence of the Degree to which the Stream is Double-Phase (K) on the Axial Parameters of the Stream on the Cross Section of the Nozzle.

The fact that the nature of the change in the axial parameters along the axis of the stream is independent of the presence of a condensed phase indicates that the mechanisms of heat transfer and momentum in homogeneous and heterogeneous streams remain the same (in the examined variation range of the parameters). The admixture of powder to the plasma stream can lead only to a significant decrease in the absolute values of temperature and velocity of the gas.

Figure 8 illustrates the relative axial surplus temperature (Curve 1, W = 10; 15 kW) and enthalpy (Curve 2, W = 10; 15 kW) and also the relative velocity (Curves 3, 4, W = 10; 15 kW) on the cross section of the nozzle as functions of the initial degree to which it is double-phase. Along the ordinate we plotted the ratio of the axial excess temperature (enthalpy) or the axial velocity of a double-phase stream to the analogous parameters of a single-phase stream for the same operating regime.

These curves show that temperature, enthalpy and velocity of the stream decrease substantially as the degree to which the stream is double-phase increases. In the examined variation range of the working conditions of the plasmatron the greatest temperature drop is about 12%, and the greatest enthalpy drop is about 45%. It also /31 follows from the graph that, firstly, the velocity of the gas in the stream decreases substantially (up to about 30%) as the degree to which it is double-phase increases (in the examined variation range of the parameters), and, secondly, the drop in velocity takes place as intensively as the power supplied to the heater (curves 3 and 4). The latter clearly is related to the fact that with an increase in the supplied power the velocity of the flow increases (with a simultaneous decrease in the intensity of the gas), and, consequently, a large portion of the kinetic energy of the stream is transferred to the condensed phase.

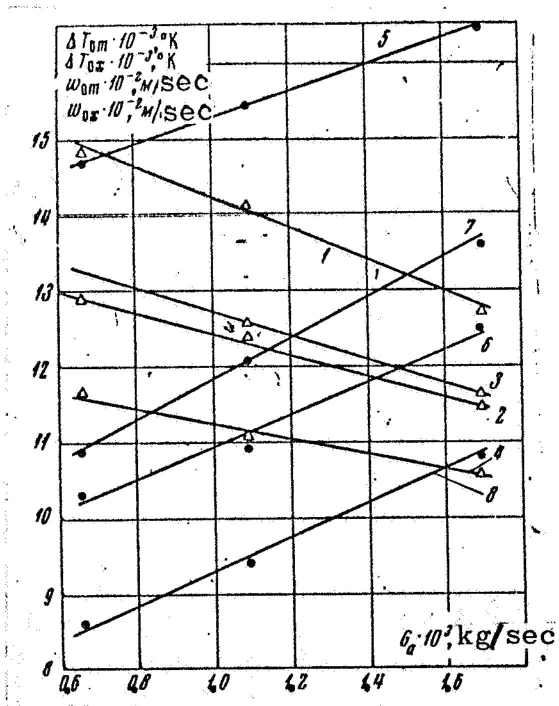

Fig. 9. The Change in the Axial Velocity and Excess Temperature on the Cross Section of the Nozzle as a Function of the Gas Flow Rate: 1, 2, 3, 4 Refer to the Change in Excess Temperature; 5, 6, 7, 8 Refer to the Change in Velocity. 1 and 5 - W = 15 kwt, G_b = 0, 2 and 6 - W = 15, G_b = $2.9 \cdot 10^{-3}$ kg/sec^{-1}; 3 and 7 - W = 10, G_b = 0, 4 and 8 - W = 10, G_b = $2.9 \cdot 10^{-3}$ kg/sec^{-1}.

Figure 9 shows the change in the axial velocity and temperature on the cross section of the nozzle (for single-phase and double-phase flows) as a function of the argon flow rate. As we can notice (Fig. 9) the velocity of both single-phase and double-phase streams increases as the gas flow rate increases. However, the axial velocity in a heterogeneous stream increases somewhat more intensely than in a homogeneous stream, which is related to the decrease in the degree to which it is double-phase of a heterogeneous stream (in view of the fact that G_b = const). The excess axial temperature (Fig. 9), on the other hand, decreases as the flow rate with a given power increases. The temperature drop in a double-phase stream is less intensive than in a single-phase, which is explained by the decrease in the degree to which the stream is double-phase with an increase in the flow rate of the working medium.

In conclusion the authors wish to thank L.S. Polak for his numerous valuable discussions of the results of my work.

References

1. Abramovich, G.N.: Teoriya turbulentnykh struy (The Theory of Turbulent Streams). Fizmatgiz, 1960.
2. Vulis, L.A. and V.P. Kashkarov: Teoriya struy vyazkoy zhidkosti (The Theory of Streams of Viscous Fluid). "Nauka" Press, 1966.
3. The collection: Kinetika i termodinamika khimicheskikh reaktsiy v nizkotemperaturnoy plazme (Kinetics and Thermodynamics of Chemical Reactions in a Low-Temperature Plasma). (L.S. Polak, ed) Nauka Press, 1965.
4. Gray, D. and P. Jacobs: Raketnaya tekhnika i kosmonavtika, No. 3, p. 25, 1964.
5. Gray, D. et al.: Raketnaya tekhnika i kosmonavtika, No. 6, p. 36, 1966.
6. O'Conner, T. et al.: Raketnaya tekhnika i komonavtika, No. 11, p. 181, 1966.
7. Gordov, A.N.: Osnovy pirometrii (Fundamentals of Photometry). "Metallurgiya" Press, 1964.
8. Prokof'yev, V.K.: Fotometricheskiye metody kolichestvennogo spektral'nogo analiza metallov i splavov (Photometric Methods of Quantitative Spectral Analysis of Metals and Alloys). State Technical and Theoretical Press, 1961.
9. Drawin, H.: Z. Phys., Vol. 146, p. 294, 1965.
10. The collection: Izmereniye nestantsionarnykh temperatur i teplovykh potokov (The Measurement of Nonstationary Temperatures and Heat Flows). (A.N. Gordov, ed.) "Mir" Press, 1966.
11. Gorlin, S.M. and I.I. Schlessinger: Aeromekhanicheskiye izmereniya (Aeromechanical Measurements). "Nauka" Press, 1964.
12. Kimura, I. and A. Kanzava: Raketnaya tekhnika i kosmonavtika, No. 3, p. 122, 1965.
13. Inkropera et al: Raketnaya tekhnika i kosmonavtika, No. 6, p. 164, 1966.
14. Kratkiy tekhnicheskiy spravochnik (A Short Technical Handbook). (V.A. Zinov'yev, ed.). Pt. 1, State Technical and Theoretical Press, 1949.

Translated for the National Aeronautics and Space Administration by:
Aztec School of Languages, Inc.
Research Translation Division (479)
Maynard, Massachusetts
NASw-1692